

Observations Of Waves And Currents Near The Surf Zone

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Award #: N00014-90-J-1285

LONG-TERM GOALS

The goal is to understand the form and dynamics of the various flows and exchanges near shore. These flows are forced mainly by waves and wind, with weaker influences due to larger scale flows (e.g., freshwater outflow from Chesapeake Bay, etc.). The dynamics near shore are also influenced by topography, strongly affecting both the wave field and the circulation itself. Such understanding should lead to predictions of the features such as instabilities and rip currents, the net effects on horizontal mixing and diffusion, and the feedback on morphological evolution and beach erosion. To understand this complex system, a reasonable approach is to focus on times and places where one or just a few of the influences dominate, until each is understood well enough to combine into a unified theory of nearshore dynamics.

OBJECTIVES

The scientific objective is to classify the observed circulation conditions (e.g., in terms of the mean square vorticity, the RMS variability of the observed flow field, or the occurrence and strength of “rip currents”) and relate these observed conditions to forcing by wind and waves. Two relevant hypotheses are that (1) rip current activity is associated with cuts or channels in the nearshore sandbar, and (2) they are associated with nearly normal incidence of the waves. In addition, it is (newly) hypothesized that conditions of swell incident at an angle opposing the wind-driven flow leads to stronger variability in the flow.

A technical objective is to establish real-world error bounds on the velocity estimates from the Phased-Array Doppler Sonars (PADS), and the effective depth of these measurements. Due to their quasi-continuous areal coverage, these measurements appear suitable for evaluation of (and hence investigation into the dynamics of) the vertical component of vorticity of the nearshore currents. The essential method is to project short “pings” of sound in a 90°-wide horizontal fan (filling the water column in shallow water). The sound scatters off both the near-surface bubble layer and the bottom (and anything else in the water). Some backscattered sound returns to the sonar, where the signal is received on an array, beamformed into returns from discrete directions, and analyzed for the mean Doppler shift versus elapsed time since transmission. For direct-path transmission and return, the time-delay since transmission simply translates into distance from the sonar. The bottom reflections are generally much weaker, but are independent of the wind/wave conditions, and can become significant when the wind and waves are so weak that too few bubbles are generated. Also, the surface wave field strongly modulates the acoustic “waveguide.” The concern is whether these acoustic effects distort the signal sufficiently to make interpretation of the measurements difficult.

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE 30 SEP 1999		2. REPORT TYPE		3. DATES COVERED 00-00-1999 to 00-00-1999	
4. TITLE AND SUBTITLE Observations Of Waves And Currents Near The Surf Zone				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) University of California, San Diego, Scripps Institute of Oceanography, 9500 Gilman Drive, La Jolla, CA, 92093				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 6	19a. NAME OF RESPONSIBLE PERSON
a REPORT unclassified	b ABSTRACT unclassified	c THIS PAGE unclassified			

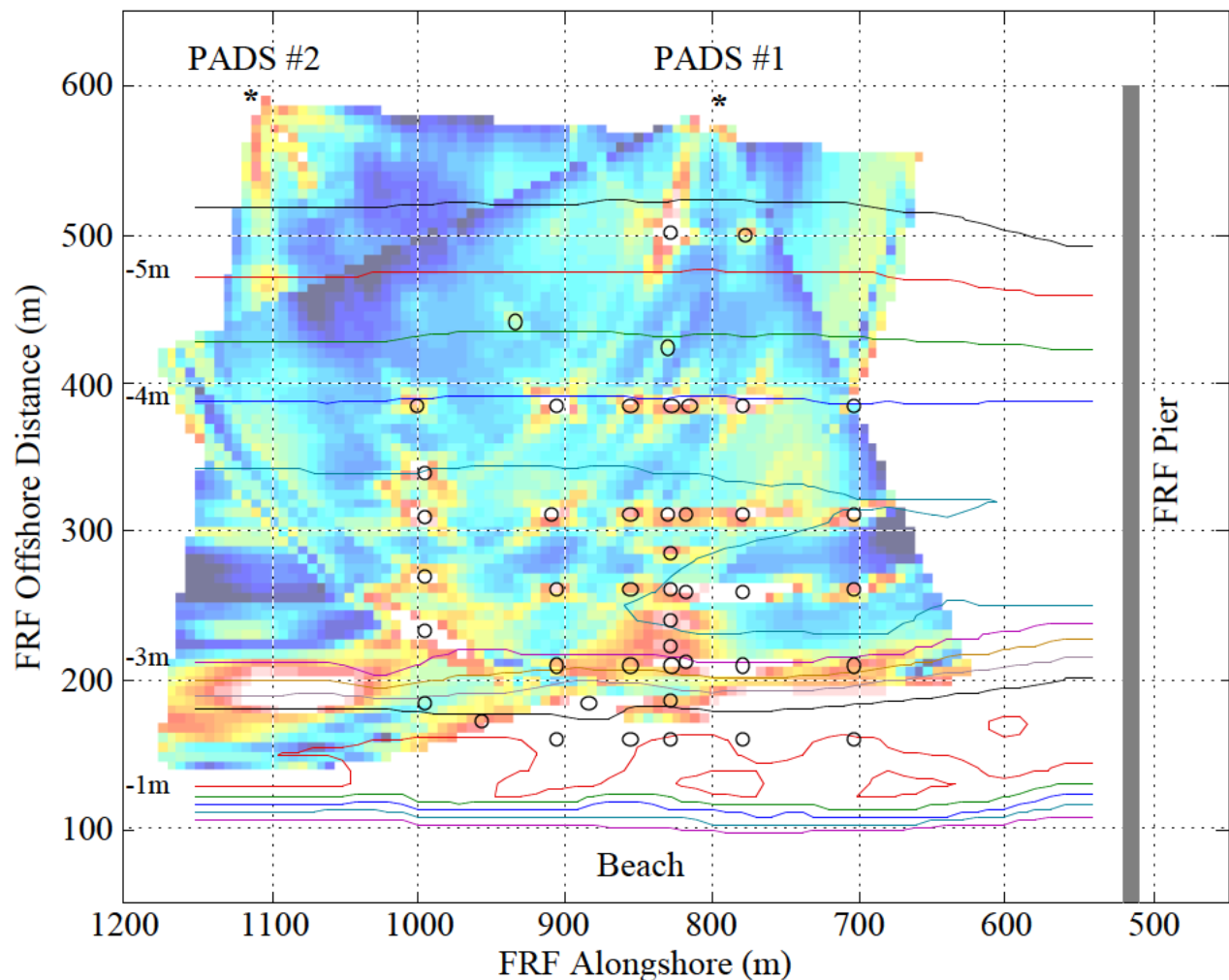


Figure 1. SandyDuck experimental site, showing the areas covered by the Phased Array Doppler Sonars (PADS). The color contours show the mean intensity from both sonars; red and white indicate the most, blue and black the least backscatter. The circles show locations of frames with current meters (etc.); note that these frames show up as “bright” scatterers. North is about 20° clockwise of left. The location is the Field Research Facility of the US Army Corps of Engineers, in Duck, North Carolina.

APPROACH

The first technical requirement is verification and calibration of the phased-array Doppler sonar (PADS) measurements. Items to be considered include the partial backscatter from the bottom, interference from acoustically bright structures, and the net effect of the surface waves (e.g., sheltering within peaks, effects of extreme slopes and displacements). Data from discrete locations within the PADS viewing area are being used for direct comparisons. Near-bottom currents have been provided by S. Elgar et al., and current profiles in 25-cm vertical bins have been provided by P. Howd for this purpose. Wave motions, which penetrate in a predictable way to the bottom in finite-depth water, can be compared at all available sensor locations. This comparison is undergoing detailed evaluation versus both frequency and range. For the lower frequency motions, such as shear-waves and eddies associated with the alongshore shear, the correspondence between near-surface and near-bottom measurements can vary depending on the stratification. The profile data has been used to evaluate the depth of the strongest correlation with the PADS data, and the correlation with various depth-weighted

averages. Where there is strong vertical mixing, currents near the bottom correlate well with the near-surface currents. In contrast, when there is stratification the correlation can become small, with mean angles over 45° between the top and bottom.

The simplest model for transforming the "raw" acoustic data into maps of velocity and scatterer density appears adequate to begin concurrent work on the scientific objectives. The first step is to classify the observational periods at SandyDuck in terms of the observed flow conditions and the concurrent wind and wave conditions. The approach taken here is to examine averaged indicators of flow activity. For example, the average enstrophy (mean square vorticity) should be a good indicator of the occurrence of shear waves; in contrast, the kinetic energy (mean square velocity perturbations) over 1 to 10 minute periods should be a good indicator of the total flow perturbations, including both rip currents, shear waves, and other infragravity motions. Further analysis via time-space Fourier transforms may permit separation of motions according to the appropriate dispersion relations.

WORK COMPLETED

Two "Phased Array Doppler Sonars" (PADS) were deployed as part of "SandyDuck" in 1997 (figure 1), and were operated for two months almost continuously. Each PADS measured radial velocity over a wedge up to 400 m radius by 90 degrees, with 6 m to 20 m 2D cell resolution. In the overlapping region, both horizontal components of flow are estimated. The data resolve both surface-wave motion (with 1.5 second sampling), and lower frequencies (with longer time averages achieving sub-cm/s velocity accuracy).

A first pass analysis of the data was completed in the summer of 1998, thanks in part to the help of summer intern David Thompson (who also drove the CRAB during SandyDuck). This resulted in two overviews of the data: (1) 30-second averages were formed near a high-tide and a low-tide for each day where data are available; and (2) 10-minute averaged fields were computed for two continuous multi-day segments: September 17 to 21, and October 14 to 19, 1997. These two "time-lapse" segments each span transitions from calm to moderately stormy. From these overview movies, times of interest can be selected for further analysis.

A second pass analysis involved re-averaging the data from the "wave-mode" files, to eliminate intensity-biasing and to facilitate separation of all gravity modes (including "infra-gravity" edge waves as well as the incident waves) from the vortical modes. An index of wave variance within each spatial cell and averaging period (generally of order one minute) was also formed, and is useful both technically, as a diagnostic of sonar performance, and scientifically, as an indication of the wave characteristics.

In general, averages of a minute or longer appear sufficient to reduce the gravity-mode activity to a level below the vortical-mode variance. The boundary flux of vorticity can be assessed using estimates of velocity and vorticity near the edge of the region, and accounted for in the vorticity budget. There is a sense that the dissipation of vorticity is larger inside or near the surfzone, and smaller further offshore. To make a first-cut examination of this, the measurement area was subdivided into two parts, inshore and offshore of the 4 m depth contour. The notion that the nearshore vorticity dissipates more rapidly than that offshore is born out in this calculation. In one particularly striking example, an offshore feature resembling a "vortex pair" propagates through along the 5 m contour, leaving behind a "tail" of negative vorticity; this remnant tail persists after the feature exits the other boundary, and

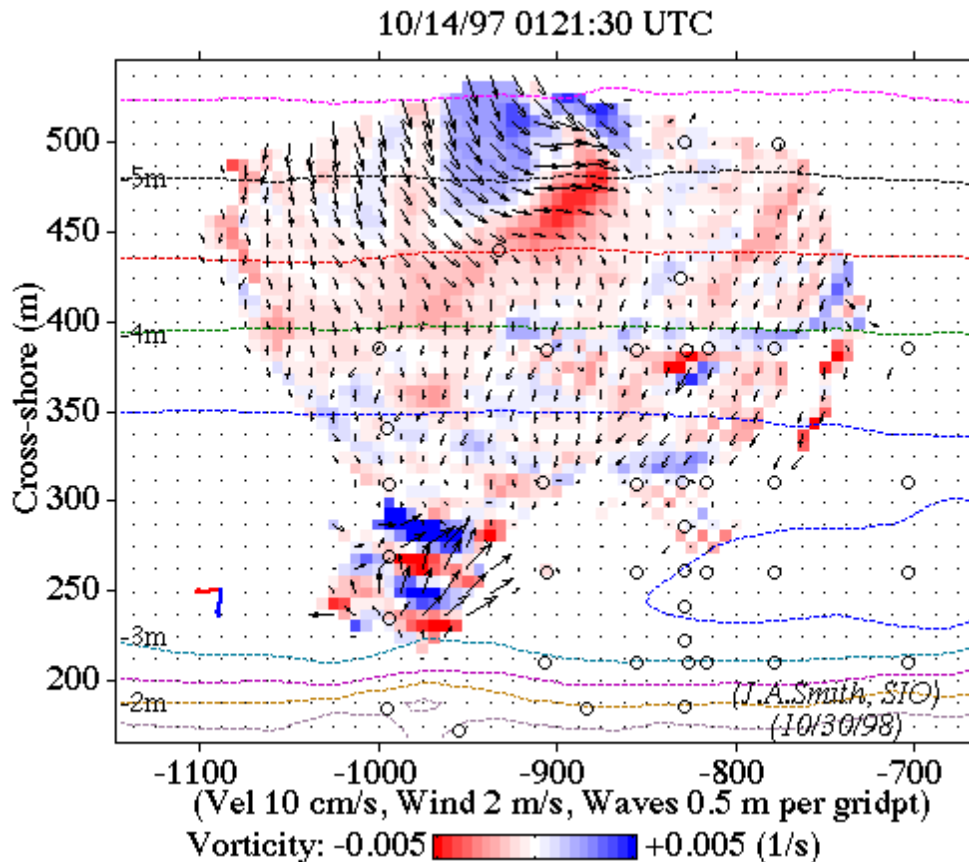


Figure 2. Horizontal velocity vector estimates (black arrows) and the associated vorticity (color contours) over the area covered by both PADS. Two features are seen. The upper feature resembles a “vortex pair,” and moves through from left to right roughly along the 5-m contour. The strength remains fairly constant, but it leaves behind a “trail” of red (–) vorticity along the –4.5 meter depth contour. The lower feature may be a rip current originating near a gap in the sandbar. This propagates some distance into the domain, but fades quickly. A red arrow at lower left shows the wind speed (1.5 m/s) and direction, blue arrow shows significant wave height (0.5 m) and direction. At this particular time the flow opposes both wind and wave directions alongshore. [movie available at <http://jerry.ucsd.edu/vort1014.MOOV>]

decays with about a 20 minute time-scale. In contrast, the occasional offshore “squirts” seen in the shallower sub-region decay too rapidly to measure well, lasting only a few minutes.

Vortex generation and detachment apparently do occur near shore. While the former is probably quite common, persistence of the latter (isolated vortex pairs) appears to be rare. These detaching vortex-pairs are more likely to occur during low winds and low to medium waves. The most striking example (figure 2) occurs during the unusual conditions of offshore flow opposing both wind and waves.

In wind and wave dominated conditions, the Eulerian velocity has a distinct offshore component. In contrast, the Lagrangian drift, as indicated by the motion of bubble clouds (not shown here) is shore-parallel. The difference may be accounted for by the Stokes' drift of the waves [Smith 1998, Smith 1999a, Smith 1999b]. This is apparently a significant term in the nearshore mass balance.

There is a sense that the dissipation of vorticity should be larger where wave breaking occurs, and smaller further offshore. To make a first-cut examination of this, the measurement area was further subdivided into two parts, inshore and offshore of the 4 m depth contour. The notion that the near-shore vorticity dissipates much more rapidly than that offshore is born out in this calculation. In one particularly striking example, an offshore feature resembling a "vortex pair" propagates through along the 5 m contour, leaving behind a "tail" of negative vorticity; this remnant tail persists after the feature exits the other boundary, and decays with about a 20 minute time-scale. In contrast, the occasional offshore "squirts" associated with rip-current activity (in the shallow sub-region) decay too rapidly to measure well, lasting only a few minutes. A first-pass survey of the data indicates that the former (a discrete offshore vorticity feature) is rare, while the latter (rip-current-like "squirts" coming off the inner bar) are sporadic but not uncommon.

RESULTS

Comparisons between PADS and other current measurements so far is encouraging, with correlations typically in the range of 0.90 to over 0.99 (depending on the measurements being near-surface or near-bottom, and on the existence of stratification). The depth of measurement most tightly correlated with the PADS estimates is near 1.2 m below the surface (mean with respect to waves, moving with the tide). At surface wave frequencies, cross-spectra show high correlations up to frequencies of about 0.2 Hz. Higher frequency waves have wavelengths comparable to the 20 m averaging scale of the measurements (i.e. less than 40 m).

Vortex generation and detachment apparently do occur near shore. While the former is probably quite common, persistence of through the latter appears to be rare. The early indications are that the highly nonlinear regime indicated by detaching vortex-pairs is more likely to occur during low winds and medium waves. The most striking example (figure 2) occurs during the unusual conditions of offshore flow opposing both wind and waves.

In wind & wave dominated conditions, the Eulerian velocity has a distinct offshore component. In contrast, the Lagrangian drift, as indicated by the motion of bubble clouds (not shown here) is quite tightly shore-parallel. The difference would likely match the computed Stokes' drift of the waves [cf. *Smith* 1998]. This is apparently a significant term in the nearshore mass balance.

IMPACT/APPLICATIONS

One day it should be possible to predict the nonlinear regime of the flow: Will there be rip currents today? How much on/offshore mixing may we expect? Are the conditions conducive to sediment transport? To build this ability, we need a data-base covering a variety of conditions, both in forcing and response, with sufficient time-space coverage to provide the needed measures of the flow.

The means by which we have viewed the velocity and vorticity fields in this study is novel. Patterns suggestive of vortex dynamics (e.g., a self-propagating vortex pair) have been observed in the nearshore environment for the first time. The PADS measurements are a natural complement to the discrete arrays of high-precision current meters, pressure sensors, (etc.) deployed within and near the surf-zone. As a data-base of conditions and response is built up, we can begin to extensively test our models and improve our predictive ability.

TRANSITIONS

Possible input to numerical models of both waves (e.g. FUNWAVE, J. Kirby) and nearshore circulation (e.g., Slinn & Allen, Dalrymple, etc.). Now in "serious talk" stage.

PADS technology may transition to other uses contingent on its verification as a valid measurements. Areas where there is interest include monitoring of waves and currents at inlets and harbors.

RELATED PROJECTS

An acoustics project (under the ARL program) used one PADS to look upwards at the structure of bubble clouds in the open ocean (breaking waves), using it in a high-resolution short-range mode from FLIP.

Future projects include open ocean measurements of waves and Langmuir circulation, and the possible participation in an experiment focusing on waves and currents over the head of a submarine canyon (NCEX).

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PUBLICATIONS

Rieder, K. F., and J. A. Smith, Removing wave effects from the wind stress vector, *J. Geophys. Res.*, 103, 1363-1374, 1998.

[& see above]

PATENTS

Paperwork toward patenting PADS technology has been registered.